



Innovation 2050

A Digital Future for the Infrastructure Industry

June 2017



About Balfour Beatty

Balfour Beatty is a leading international infrastructure group. With 30,000 employees, we finance, develop, build and maintain the vital infrastructure that we all depend on. From our beginnings in 1909 we have grown to become an international business. We are one of the few companies with the skills to deliver complex projects of huge scale and take advantage of the growth in long-term infrastructure markets. Our impact is in iconic structures, bold engineering feats, behind-the-scenes innovation and joined-up thinking – financing and partnerships that make up the world's great infrastructure projects today.

For us to continue leading the industry, it is essential that we focus on innovation. To fuel this drive for continuous improvement, our innovation and technology teams are focused on research, development and the deployment of leading-edge best practices, lean processes and technologies that help us deliver higher quality, more efficient and cost-effective solutions.

Balfour Beatty has made significant progress in its vision to become a truly digitally empowered business. Development of internal expert capabilities such as the training of new Drone Pilots, a digital surveying team with full laser scanning service, a high-end visualisation team and a significant increase in BIM related skills has shown an increase in quality, a leaner approach and a safer working environment. In 2016, we undertook global collaboration in the fields of virtual reality and construction robotics, using skills from the UK, USA and Hong Kong. Both technologies are vital to the future of Balfour Beatty and the industry as a whole.

Balfour Beatty's commitment to a digital future will continue beyond 2017 through constantly improving our internal capability, partnering with the best creative minds from the technology world and being bold in the adoption of new and emerging technologies.

Executive summary

The construction site of 2050 will be human-free. Robots will work in teams to build complex structures using dynamic new materials. Elements of the build will self-assemble. Drones flying overhead will scan the site constantly, inspecting the work and using the data collected to predict and solve problems before they arise, sending instructions to robotic cranes and diggers and automated builders with no need for human involvement. The role of the human overseer will be to remotely manage multiple projects simultaneously, accessing 3D and 4D visuals and data from the on-site machines, ensuring the build is proceeding to specification. The very few people accessing the site itself will wear robotically enhanced exoskeletons and will use neural-control technology to move and control machinery and other robots on site.

Today this vision may seem far-fetched. But consider the complex tasks performed by robots in a modern factory and it is not so hard to imagine such a future for the construction site. Indeed, in many areas of life the robots are not coming, they are already here. From automated tills in supermarkets, to autonomous vehicles on roads and voice-activated technologies in our homes, digital technologies are changing the way we work, shop, travel and relax, how we interact with the world around us and how we think about, commission and build our infrastructure. These technological changes bring significant opportunities for transformational change in the infrastructure industry. Balfour Beatty believes that the rise of digitisation and robotics in

construction will bring about a huge increase in productivity in what is a very large but historically low-productivity sector. It will increase efficiency, solve the issue of skills shortages faced by countries around the world and take the danger out of building, making Zero Harm a reality.

What is the driver behind these changes? Infrastructure is a political and economic priority in many countries across the world. Increasingly complex projects are being commissioned to stimulate sluggish economies, upgrade old systems and cater for growing and changing populations. With high economic growth and fast-growing populations leading to significant urbanisation, the demand for new infrastructure is predicted to see massive growth in coming decades. Other new challenges: changing demographics; the increasing expectations of businesses, service users and the public; and the need to reduce carbon emissions and waste, all create a dynamic and testing environment for the industry and those commissioning new projects.



Adopting and mainstreaming digital and other new technologies, such as advances in robotics and artificial intelligence, will be a game-changer for the industry, speeding up the otherwise slow-and-steady modernisation of the sector, and providing answers to the challenges and opportunities we face. The benefits of digitisation are clear to companies such as Balfour Beatty, which is already using them across the business and the projects it is working on. Projects can be delivered more effectively and efficiently by harnessing the power of cloud computing and enhanced mobile technology. Building Information Modelling (BIM) in the form of 3D digital representation of projects overlaid with 4D detail on scheduling and cost, together with augmented and virtual reality technology enables seamless interaction between offices and sites facilitating a “build right first time” approach. Drones allow teams to track progress safely, more efficiently and with increased accuracy, collecting data more frequently than human surveyors. Telematics are tracking how our vehicles are used, ensuring that we drive them economically, safely and sustainably. And we are using data analytics to begin to predict and prevent problems as they arise in infrastructure, rather than the slower, more expensive and less reliable “find and fix” model the industry has relied on for decades.

Looking to the future and beyond the humanless construction site, there are a number of other predictions we can make, something which we do later in this paper. We are already using intelligent transportation systems (ITS) in the form of sensors embedded in traffic lights, car parks, roads and bridges to regulate traffic flows and smart buildings, with lighting which dims or switches itself off in areas where no one is moving. In the future, the Internet of Things will power smart buildings built with new, self-healing, energy generating or breathable materials, in smart cities which are able to model the future and adapt instantly to changing circumstances; construction will get faster, with the advent of 3D printing of bespoke components and even entire buildings, and 4D printing where self-transforming objects respond to changes in heat, sound or moisture levels to change shape; wearable technology will reduce worker injury and improve worker health while increasing productivity; and there will be a whole host of other new innovations which we must be ready for, both in terms of regulation and also in terms of skills.

Of course, cutting edge technologies and accelerating change will provide us with challenges as well as opportunities. With increased digitisation, the risk of cyber-attack becomes more likely as the world has seen already in May 2017 with the “WannaCry” ransomware attack – the worst global incident to date. The high levels of energy required by increased data usage and storage will also begin to have a significant impact on resources within the next decade. And we will begin to see a dramatic increase in competition for “digital natives”, those who grew up in the digital age and are able to combine digital skills with creativity and new ideas. Companies across the world will need to step up to the plate and ensure that they have the infrastructure and policies in place to counter these challenges.

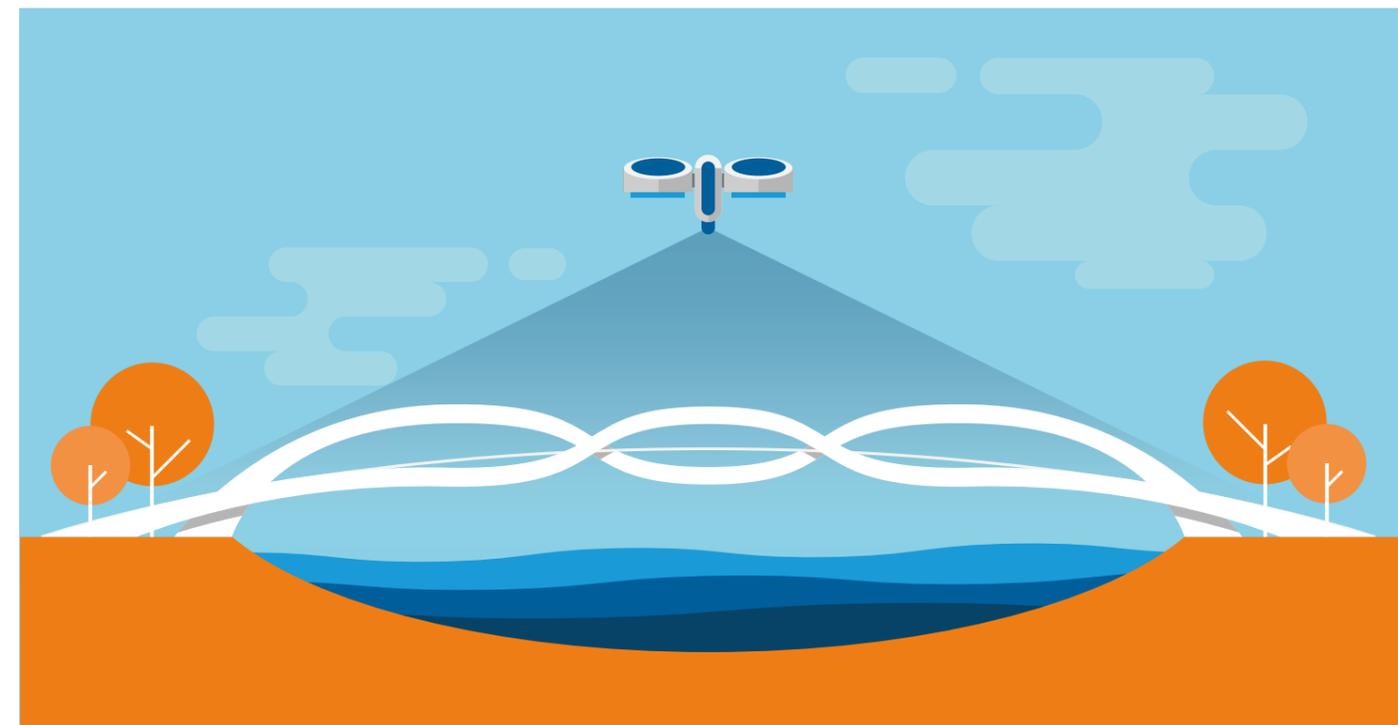
So where does this leave the infrastructure industry as it looks today? The landscape is likely to change significantly and the industry will evolve as the disruptive change that has impacted other industries also takes hold in ours. New business models are already emerging which will drive customers to change how they procure new infrastructure and drive companies to mainstream digital. Commissioners will begin to work directly with disruptors. Payment methods and incentives will change. This will require large infrastructure and construction companies to increasingly balance their existing offer with innovating and nurturing new ideas, something which many large organisations with standardised, controlled processes often struggle to do successfully¹. Policy makers and regulators will need to ensure that they are ready for the changes, as will the industry, which is why Balfour Beatty is investing in digital and in the skilled workforce that goes along with it.

Change in the industry is overdue. The digital revolution will redefine the sector. It will lead to a reshaping of business strategies, a reimagining of our offering to the customer and a shift in the kind of roles infrastructure companies recruit for. For companies to capitalise on it, the digital transformation cannot be the preserve of one specific team – it must encompass the whole organisation. More than that, it must be pushed down the supply chain to maximise the benefits. Use of the latest digital technology and tools has to become the norm rather than the exception. We must respond and embrace the transformation that new technology can provide so we can deliver the infrastructure of the future.

¹ The Ambidextrous Organisation concept, Charles O'Reilly, Stanford Graduate School of Business

Our ten predictions for 2050

- 01** The industry will become increasingly focused on innovation and both contractors and customers will become less risk-averse.
- 02** The shape and offer of the infrastructure industry will change significantly, with new business models, products and services.
- 03** Infrastructure will move on from concrete and steel to include new materials which respond to their surroundings.
- 04** New jobs and industries will be created – and some will disappear, especially low or zero skill roles and those relying on repetition of tasks.
- 05** Thinking only about design and construction will become an outdated concept as infrastructure becomes multi-functional.
- 06** Robots will become more prevalent in construction.
- 07** Construction will get faster, using 3D and 4D printing, and self-transforming objects which self-assemble.
- 08** New, disruptive ideas will emerge, for making mass transit faster, safer and less damaging to the environment.
- 09** We will increasingly use more wearable technology such as exoskeletons.
- 10** Direct neural control over devices and vehicles will be accessible to the industry.



New technologies will be used in the creation of infrastructure

Recommendations

01. The construction and infrastructure industry must become more agile – Tier 1 contractors will need to become disruptors

The business landscape will become less defined and predictable and there will be more cross-industry competition as companies try new models and products and develop multiple fields of expertise. Pan industry partnerships will emerge between large technology players (Amazon, Google, Microsoft), bespoke SMEs and construction businesses as the market for ConstrucTech emerges. Incumbents will therefore have to become agile – there will be no room, or time, for complacency. Companies which have relied on one, traditional approach will need to themselves become disruptors or put in place strong strategies to avert the disruption.

02. Cyber risk must be taken seriously and programmed in

Governments will have to scale up and invest in national cyber defence programmes to protect critical infrastructure. However the infrastructure industry must take its share of responsibility in tackling these issues. It must ensure that data is treated as a major asset. Cyber risk has to be programmed in, much as any other risk would be. Governance must be strong and best practice embedded and rigorously followed. Employees must be properly trained and security software kept up to date.

Customers will rightly become increasingly demanding on cyber-security compliance and the legal implications, given the significance of some of the data involved, are significant. The infrastructure industry must take the risks seriously and be proactive in tackling them.

03. Infrastructure companies will need to balance the benefits of increasing the amount of data they collect, with privacy concerns

Demands for regulation around privacy are likely to escalate, and infrastructure companies embedding sensors will need to ensure that they respond to the privacy challenge by ensuring the highest levels of encryption and anonymisation.

04. The sector will need a more agile workforce with new skills

The sector will need a more dynamic, agile workforce, skilled at challenging conventional solutions. This means that education systems around the world will have to respond to the challenge of teaching students the skills to solve problems that have not occurred or even been imagined.

The infrastructure and construction industry will also have to improve its image and to explain the wide range of exciting and challenging roles available, in order to attract the skilled individuals it needs to undertake its digital transformation.

05. Customers must encourage and support innovation

Customers must demonstrate courage and help companies adopt new technology by, for example, examining the incentives, both regulated and non-regulated, that govern infrastructure networks, in order to address the fact that they often promote low risk behaviour and impact on procurement processes.

Overly-detailed specification should be challenged where it prevents greater innovation and hinders suppliers in adapting to unexpected challenges which emerge once contracts have been signed.

Barriers to developing and accepting innovative ideas must also be challenged and regulators and other key players should be encouraged to facilitate innovation, while those companies which pioneer innovative new ways to drive efficiency while maintaining quality should be drawn out for reward.

06. Companies must drive digital throughout the business and supply chain

Companies that commit to digital have to change the way they design, procure and build. They must take a strategy-based digital approach and drive it across the business, changing and improving the way the business operates and interacts with its customers.

Digital transformation cannot be the preserve of one specific team. It must be integral to the whole business at every stage, owned by those in leadership positions, in particular. Ensuring that the digital strategy is adopted throughout the supply chain will be key to ensuring that the value of the changes is maximised.

07. Regulatory systems must be ready for the change

To be able to embrace new technologies as they emerge, countries around the world need to be ready with the various regulatory frameworks required and infrastructure and construction companies need to ensure that they have the skills, knowledge and systems in place to build the associated infrastructure.

08. Infrastructure owners and designers, regulators and policy makers will need to ensure energy systems are ready for the digital revolution

Infrastructure design will need to take account of climate projections and impacts as the number of sensors in the world increases exponentially, putting pressure on energy systems. The use of renewable energy may need to significantly increase and new technologies and ways of storing data will have to be developed.

To play their part in this, regulators and policy makers will themselves need to upskill and ensure that they are providing frameworks which allow industry and digital solutions to flourish, while incentivising the development of new energy solutions and ensuring that resources are not irrevocably depleted.

09. Infrastructure companies must be prepared to process and use huge amounts of data

For the construction and infrastructure industry, aggregating and making sense of significantly increased volumes of data being continuously generated by a wide range of sources will require new software and algorithms, skilled data analysts, better information management and insight and the creation of mega databases which understand every part of the built environment. Data gathering and storage will have to become more intelligent to ensure that information is being used to drive improvements in the way systems operate and infrastructure is used and built.

10. Future-proof new infrastructure as it is built

The digital technologies used to operate and maintain infrastructure will continue to evolve once the infrastructure has been built. Infrastructure owners and operators will therefore need to develop strategies to integrate and use different generations of technology as well as Intelligent Information, effectively managed and reused.



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The workforce of tomorrow
will need new skills

The benefits of change

The infrastructure and construction industry is at a crossroads. It faces a number of existing and emerging challenges. By contrast with other industries, which have successfully harnessed technological advances to improve and reshape their products and services, the infrastructure sector has not yet embraced the full potential of the latest techniques and tools. Indeed, it remains surprisingly low-tech, with relatively low levels of automation. Meanwhile, productivity in the global infrastructure sector is among the worst of any industry, having remained static at 1% for the past 20 years². Profit margins are often wafer thin, and the industry is facing a critical skills shortage in many countries, due in part to its 'old-fashioned' image.

Balfour Beatty believes that technology offers the chance to reshape the industry and help it to step up and address some of these challenges, turning them instead into opportunities in the following ways:

Addressing skills shortages

Infrastructure investment has a well-documented economic multiplier effect³ and significant, large-scale projects are likely to continue to be commissioned to help rebalance and boost economies around the world. The global population is also growing, predicted to reach 9.7 billion in 2050⁴, while the way we live is changing, with two thirds of the global population predicted to live in cities by 2050⁵. Meanwhile, the expectations we have of our infrastructure and how we want it to perform, continue to grow. To meet the needs of these growing, changing, more demanding populations, we will need more infrastructure. New infrastructure. Smarter infrastructure. However, these demands will place pressure on an industry which is already facing a skills shortage in many countries.

Balfour Beatty believes that continued investment in new technologies will help address these skills shortages, by helping to change outdated perceptions of the industry, enabling us to attract a more diverse, skilled labour force. Increasing use of robots and automation will also mean that the industry becomes more productive, creating new roles for skilled workers in

cutting-edge areas, while reducing the need for those undertaking repetitive, manual tasks⁶ such as bricklaying, lessening long term health risks. Similarly, moving to off-site construction techniques such as precasting, prefabricating and preassembly has the potential to address the shortage of skilled labour while also maximising efficiency, consistency and precision and improving health and safety. As a consequence, the industry's productivity is likely to significantly increase.

Indeed, we are beginning to see customers welcoming our use of technology, especially drone surveys, the use of BIM and off-site construction, to replace more labour-intensive options, although some customers are more receptive to new solutions than others.

Delivering for the customer

Customers will always, rightly, expect contractors to demonstrate fiscal restraint, reducing construction costs where possible, while improving project delivery and safety. Balfour Beatty's view is that new technologies, techniques and materials will enable us to improve both our offer to the customer in terms of both the design and construction phase and the life-cycle costs and performance of the infrastructure we build, over the long-term. That is why we are already offering digital features and products and introducing analytics and other new digital services to customers. Most recently, this has involved laser scanning, virtual reality walkthroughs, access control of workers via portals and interactive "as-builts" to help us deliver our service more reliably.

Virtual reality and augmented reality both have significant potential to deliver customer-focussed products. For example, rather than looking at pictures of what a scheme might look like, customers can experience it in a simulated environment in 3 or 4D. This enables them to experience the structure as if it had already been built and understand what the structure will look like before it has been finalised, so they can give more detailed and accurate feedback on the proposals before construction has begun resulting in an end product which matches, as closely as possible, the customer's requirements.

Drones can contribute to this improved customer offer, enabling detailed virtual reality walk-throughs of remote sites and ensuring decision-making based on the latest and most accurate information, by collecting high-resolution images for input into PC or cloud-based photogrammetry systems to produce 3D models

and point clouds. Companies such as Balfour Beatty that are using drones are reaping the benefits by making data-driven decisions that were not possible before and keeping the customer constantly up to date.

Digital transformation is also a challenge for the lifecycle management of infrastructure, requiring designs to be future-proofed with transformative solutions. For example, new infrastructure is being designed and built to last for decades to come, however the digital technologies used to operate and maintain it will continue to evolve. Infrastructure owners and operators will therefore need to develop strategies to integrate and use different generations of technology.

However, construction is traditionally a risk-averse industry, and innovation carries with it uncertainty and risk. This is one of the reasons the sector has been slow to embrace some innovations. Balfour Beatty believes that customers need to demonstrate courage here and help companies adopt new technology by, for example, examining the incentives, both regulated and non-regulated, that govern infrastructure networks, in order to address the fact that they often promote low risk behaviour and impact on procurement processes. Innovation represents an enormous opportunity for all parties. Overly-detailed specification should be avoided where it prevents

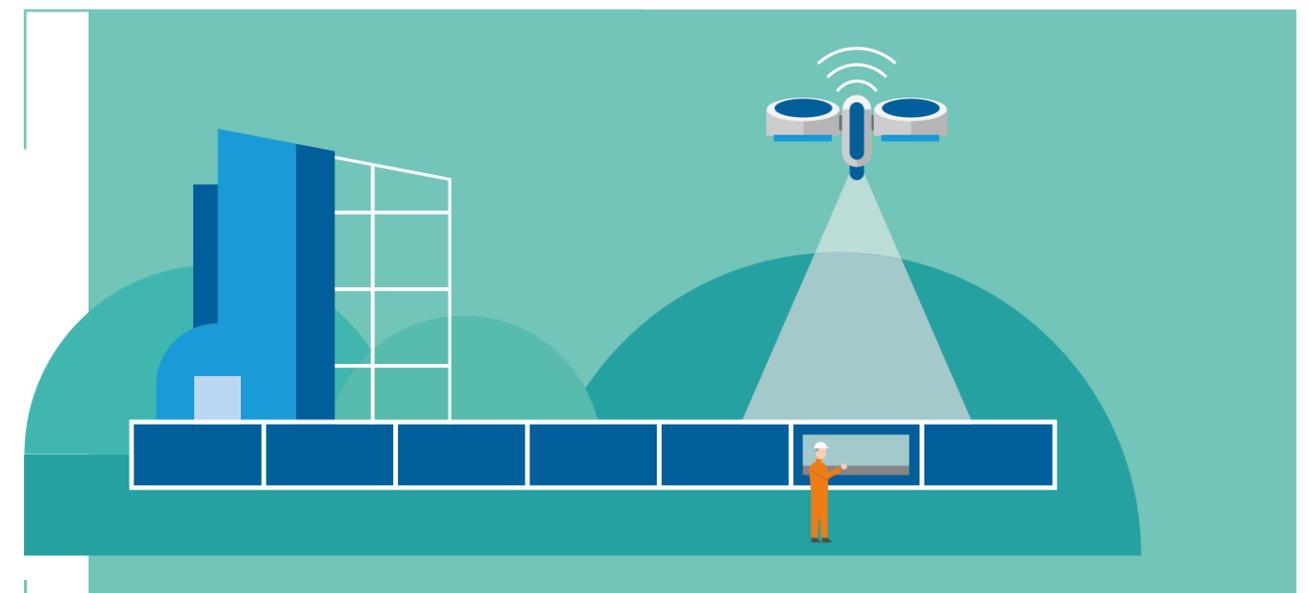
greater innovation and hinders suppliers in adapting to unexpected challenges which emerge once contracts have been signed.

Barriers to developing and accepting innovative ideas must also be challenged and regulators and other key players should be encouraged to facilitate innovation, while those companies which pioneer innovative new ways to drive efficiency while maintaining quality should be drawn out for reward.

While there will always be an element of risk in trying new techniques, Balfour Beatty believes that this should be supported by governments rather than resisted due to the risk of increased short term costs. Were governments to be 'early adopters' of new technologies and practices, this would give them endorsement it needs to win over other companies and investors.

Better collaboration

In some cases, the industry still relies on paper for things such as blueprints, design drawings and orders. This can result in sluggish progress and team members working from different versions of the same plans. However, process digitisation means moving away from paper and toward cloud-based, real-time sharing of information which integrates all elements of a project to ensure that everyone involved has access to the latest information, facilitate collaboration and improve outcomes.



Drones will collect high resolution images and data to be used in decision making

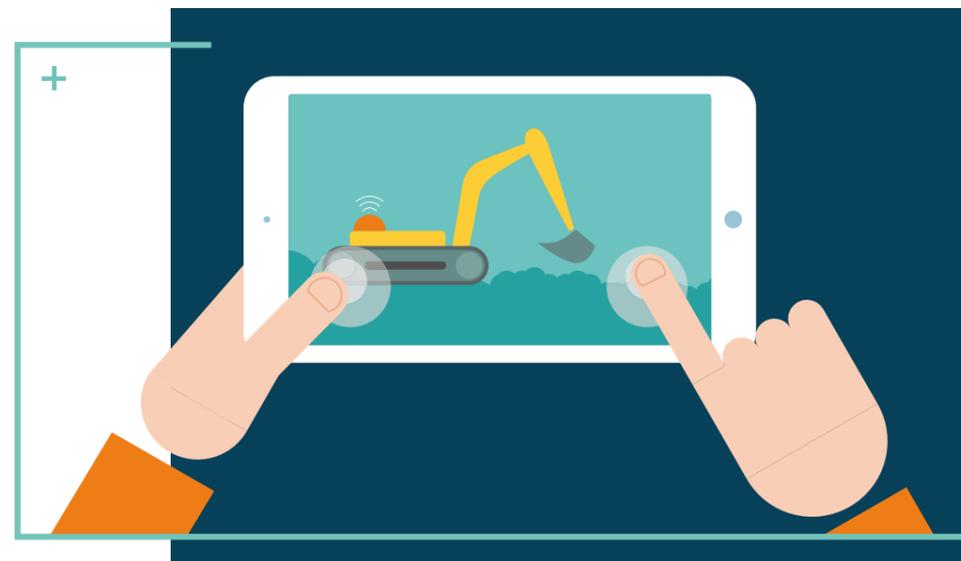
² Reinventing Construction: A Route to Higher Productivity, The McKinsey Institute, February 2017

³ For example, Infrastructure spending as a catalyst of growth and transition, European Bank for Reconstruction and Development, 05 August 2015

⁴ United Nations Department of Economic and Social Affairs, July 2015

⁵ World Urbanization Prospects, United Nations, 2014

⁶ Will robots steal our jobs? Economic Outlook, PwC, March 2017



Humans will remotely control plant and equipment

Balfour Beatty believes that online collaboration platforms offer huge potential to keep all those involved in the project informed with the most up to date information. Augmented reality in particular will increasingly mean that people can be taken into an environment where they can work collaboratively with remote colleagues, show them what they are seeing and share their experiences as if they are physically there themselves, enabling problems to be solved more efficiently and cutting travel costs and the number of people required on-site.

Improved health, safety and quality

The imperative to constantly improve health and safety and the need to deliver high quality infrastructure demands the industry continues to innovate and embrace new ideas. New technologies offer a real opportunity to do both, for example, increase automation will improve accuracy and reduce human error. Equipment with embedded sensors will also increasingly enable updates to be sent alerting teams to the fact that they need maintaining or repairing, reducing the need for “find-and-fix” in dangerous environments and therefore lessening health and safety impacts and time delays.

Balfour Beatty has been using virtual reality simulation for health and safety training. The fully immersive simulation means that we can prevent on-site accidents through better training. Featuring different real world scenarios the virtual experience gives workers the opportunity to experience live and potentially dangerous site environments, understand the space of the build, work out where heavy equipment should be placed and game plan how complex elements of the scheme can be best undertaken, from the safety of an office or training room and without the need for lengthy manuals, training sessions or specialist personnel.

Greater profitability

Increasing use of digital technologies will significantly improve the industry’s productivity. It can also help the industry address the issue of endemic low profitability. For example, the availability of real-time data enables companies to offer customers more personalised products and customised solutions, which usually generate higher margins. The ability to properly plan a large-scale construction project, where, for example, a hundred cement trucks need to access a site at the same time, by game-planning it in a virtual environment can reduce project over runs, cut costs and increase margins. The increased use of offsite, preassembled modules lowers costs and speeds up construction, offering real potential for savings for the customer and improved profitability for the contractor.

More sustainable

The infrastructure and construction sector is increasingly, rightly, being challenged to improve its environmental footprint. This will take the form of improving how it uses resources (the industry is a significant consumer of raw materials) and reduces waste and CO₂ emissions. It will also be key that we make infrastructure which performs more efficiently over the long-term. This will require new types of infrastructure, constructed differently. To assist us in this aim, Balfour Beatty is looking forward to the development of new building materials which work more in harmony with the environment, have a lower carbon footprint and are more durable, meaning less wastage and less frequent replacement or upgrading, for example, insulating gels which are also transparent can be used on buildings with large numbers of windows.

Stepping up to these challenges and maximising the opportunities will place huge demands on the infrastructure industry. In our view, it will be the digital-ready companies, the early adopters, which are best placed to respond. However, embracing digital is about more than picking a handful of new gismos. Companies that commit to digital have to change the way they design, procure and build. They must take a strategy-based digital approach and drive it across the business, changing and improving the way the business operates and interacts with its customers.

Digital is already beginning to shape business strategies and data is increasingly being used to drive business decisions. Digital transformation cannot therefore be the preserve of one specific team. It must move beyond the IT department and become organisation-wide, owned by those in leadership positions, in particular. Equally importantly, ensuring that the digital strategy is adopted throughout the supply chain will be key to ensuring that the value of the changes is maximised.



New technologies will reduce the environmental footprint of infrastructure

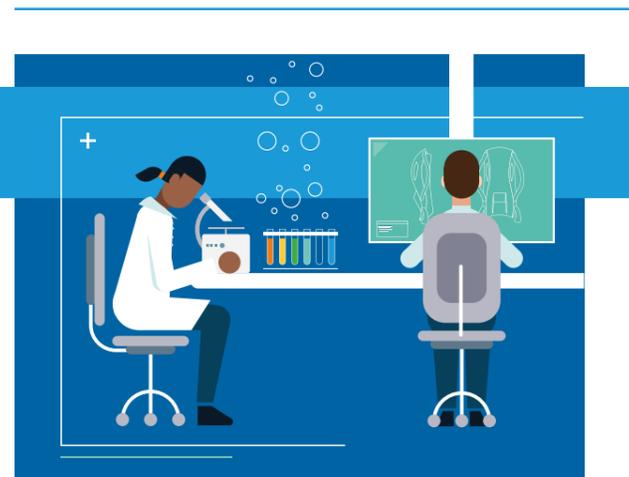
The future

Technology is rapidly redefining the infrastructure and construction sector as it is other sectors. Indeed, the scale and pace of the change as we move to more smart technology and digital solutions, is predicted to be comparable to the Industrial Revolution. While the impact these changes will have on the industry are difficult to definitively foresee, Balfour Beatty has the following ten predictions for what the industry will look like and be driven by in 2050:

01. The industry will become increasingly focussed on innovation and both contractors and customers will become less risk-averse

Competitive advantage will become something which can be taken for granted even less than it is now. As the pace of change continues to accelerate, the ability to be innovative, creative and to reimagine the business and provide solutions will become the selling point. Infrastructure and construction companies are therefore likely to become ever more focussed on horizon-scanning and innovation in the future, looking for new ways to build competitive strengths and enable the development of new products and services.

This will require courage, as new technologies are, by their nature, untested as they come online. There will be some risk involved in testing them and both contractors and our customers will have to manage that risk: we must both remain cautious and be prepared to experiment more.



The pace of innovation will be faster than ever before

02. The shape and offer of the infrastructure industry will change significantly, with new business models, products and services

Balfour Beatty predicts that the landscape of the contractor will look very different in 30 years. The disruptive change which has happened in other industries, via innovative companies such as Uber and Airbnb for example, will begin to take off in construction and infrastructure. Both of these companies have revolutionised existing infrastructure based services by providing digital platforms to connect those with supply and those with demand, rather than themselves owning and operating any infrastructure. It is possible that today's infrastructure and construction industry will see disruptors enter the market in the same way. Companies such as Balfour Beatty will therefore need to become more agile and consider their business models, potentially changing their portfolios of products and services in order to provide a personalised, next-generation offer, meet the needs of their customers and secure their market position. This will require companies to increasingly balance their existing offer with innovating and nurturing new ideas, something which many large organisations with standardised, controlled processes often struggle to do successfully⁷.

Large infrastructure and construction companies are likely to focus more on systems integration rather than a more traditional offer, as commissioners look to cut out the middle-man, seeking out smaller disruptors directly and designing new payment and incentive mechanisms for example. Companies which have relied on one, traditional approach will need to themselves become disruptors or put in place strong strategies to avert the disruption.

The sector will increase its use of data analytics to better understand customers and meet their needs, and will work more with startups to develop new solutions, new market capacity and provide solutions to problems that do not yet exist⁸. It will also begin to work more closely with the top universities around the world, to harness their talent, something Balfour Beatty has already been doing for a number of years, especially in the US, where we engage regularly with Penn State University, Stanford, University of Denver, University of Minnesota, Texas A&M, Virginia Tech

⁷ The Ambidextrous Organisation concept, Charles O'Reilly, Stanford Graduate School of Business

⁸ U.S. Department of Labor, 2013

and others on research. In particular, the research centres on digital tech use cases for enabling design and construction such as virtual reality, site safety training, virtual mockups and parametric decision making through advanced modelling.

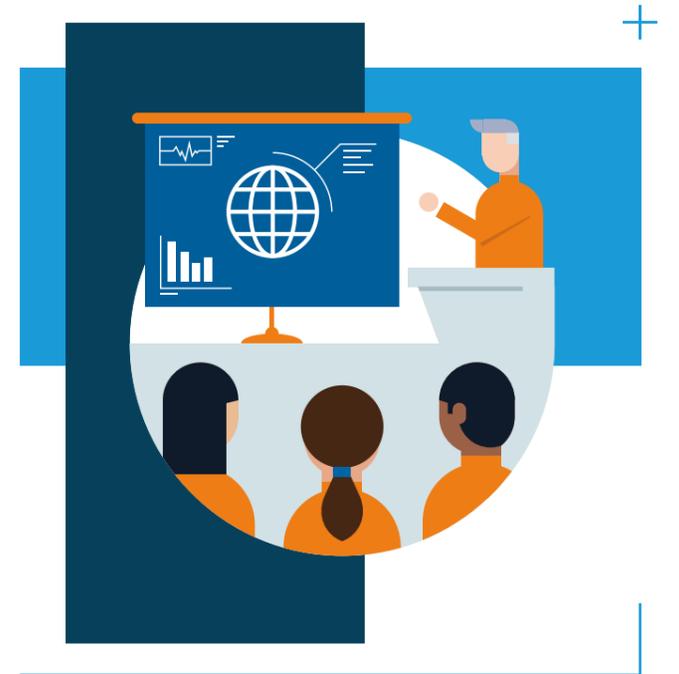
03. Infrastructure will move on from concrete and steel to include new materials

New materials technologies will come of age, bringing about massive changes to the way the built environment looks and operates. Materials such as self-healing concrete which repairs cracks without the need for humans will become standard and we will increasingly demand that our infrastructure fulfils more than one purpose. For example, kinetic technologies such as Pavegen and Lybra, which enable flooring to harness the energy of vehicles or people moving on surfaces, will become mainstream. All surfaces will become potential interface points with computers, devices and networked technology. Photovoltaic glazing, which can effectively turn whole buildings into solar panels, will also become widely used, while new materials that can respond to a variety of environmental conditions or can reduce carbon emissions from the area around them will become important.

In some cases, the technology behind these new materials has existed for some time, however their use has been limited both by lack of availability at scale in some cases, but more generally, a reluctance among customers to try new technologies, and among contractors to suggest their use.

04. New jobs and industries will be created – and some will disappear

With self-learning technologies which eliminate the risk of human error and replace humans in repetitive, unskilled roles, traditional industries such as manufacturing are likely to decline, even as new industries emerge. In the infrastructure industry, traditional roles and even entire disciplines will evolve and change. Digitisation has so far developed in ways that were not anticipated – it is likely that that will continue to be the case: twenty years ago, it was unforeseen that thousands of drone pilots and drone data analysts would be needed.

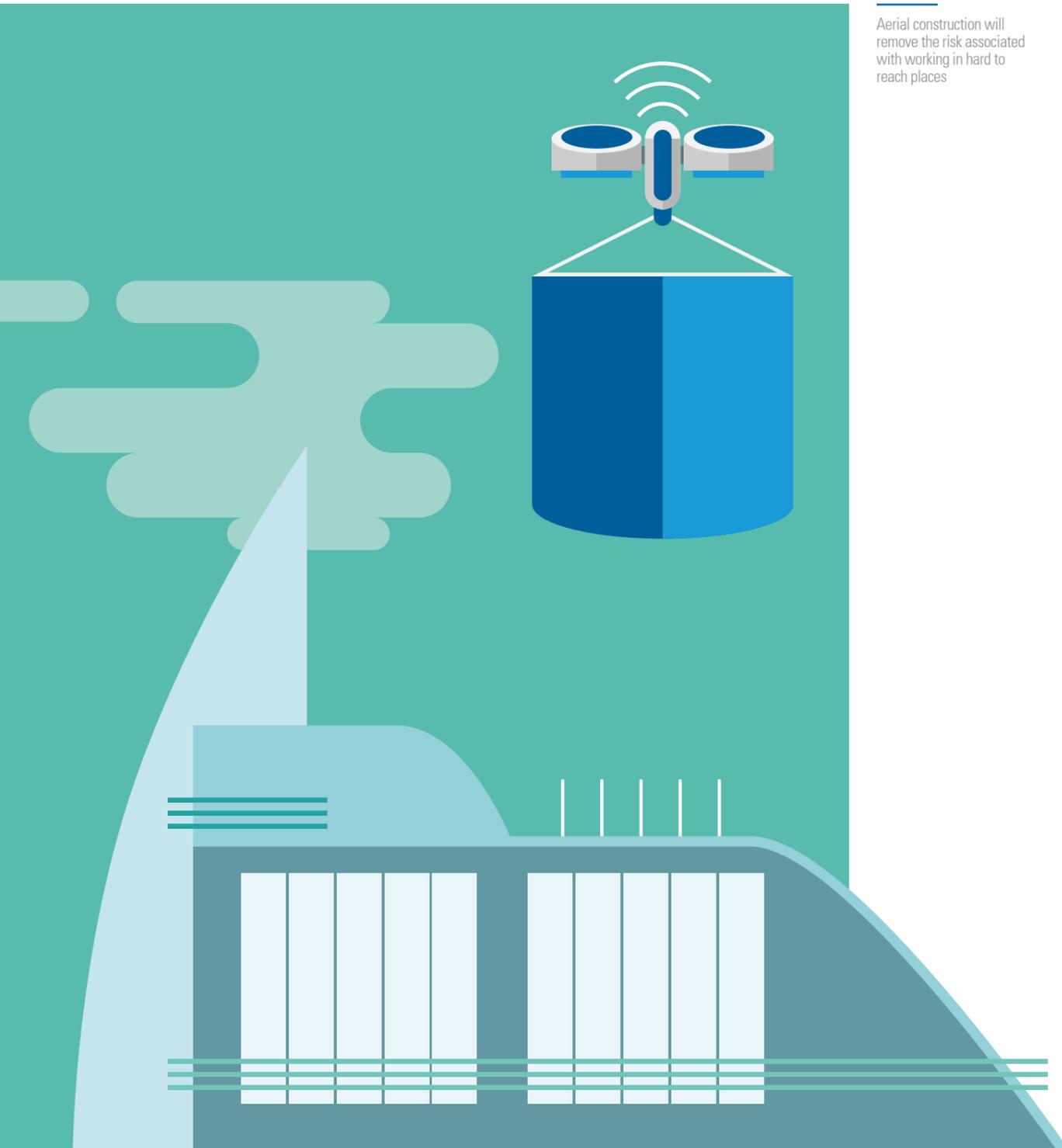


Students will need to be taught the skills required to solve problems that have not yet occurred

Looking to the future, predictions are that 65% of children at school today will work in jobs that do not yet exist. This means that this sector and others will need a more dynamic, agile workforce, skilled at challenging conventional solutions. Existing processes and structures will need to change and companies will need robust data analytics capabilities - there is little value in the data on its own. The data has to be processed and analysed so it can be used to provide intelligence which drives change.

There will therefore be significant changes to the labour market as employers begin to look for the types of skills that the workers of tomorrow will need. Technology needs human interaction to be successful, but we will have to change our expectations around roles. This means that education systems around the world will have to respond to the challenge of teaching students the skills to solve problems that have not occurred or even been imagined.

It is inevitable that technological advances and increased computerisation will put increasing pressure on low-skill, low-wage jobs. Other roles will become less labour-intensive and



Aerial construction will remove the risk associated with working in hard to reach places

require fewer workers. However, there will be a greater need for more specialist skills and we will begin to see a dramatic increase in competition for “digital natives”, those who grew up in the digital age and are able to combine digital skills with creativity and new ideas. Skilled individuals will increasingly become a differentiator and those with ideas and creativity will be increasingly valued. However, they will need to be prepared to constantly upskill and be retrained several times. The concept of a “job for life” will become a thing of the past.

In the short to medium term, there is likely to be a skills gap. With companies such as Amazon and Google currently struggling to find enough skilled staff and the infrastructure industry increasingly seeking to recruit from the same talent pool, we must work to improve the image of the industry and to explain the wide range of exciting and challenging roles in order to attract the skilled individuals we need.

05. Thinking only about design and construction will become an outdated concept as infrastructure becomes multi-functional

Machines, objects and materials are already capturing, storing and reacting to data. Data, or performance metrics, collated from networks of sensors will become increasingly important. The Internet of Things will power smart buildings in smart cities. Objects will order their own replacement parts as necessary and traffic lights will collate data and adjust traffic flows intelligently. Public transport systems will respond to congestion or need by allocating buses where people are queuing.

Balfour Beatty believes that future infrastructure designs will become anticipatory and proactive. The focus will change from delivering infrastructure which fulfills a single purpose, for example, a bridge spanning a river, and move to how the infrastructure interacts with the wider built environment and the long-term life and performance of assets.

06. Robots will become more prevalent in construction

Although limited robots are already used in construction, their use is largely restricted to roles such as diagnostics in dangerous or hard-to-reach areas. Even then, the high costs at the moment are prohibitive. Over time, the use of robots will

become more cost-effective and we will begin to see a boom in the use of robots in construction.

The increasing use of robots on-site will begin in areas involving repetitive tasks. Elsewhere it will take the form of machine-to-machine communication in areas such as remote inspection and remote site visits, or putting together preassembled modules. Machines will then begin to take on the most dangerous jobs in the industry. However, we believe that much of the actual building and construction process will be automated by 2050. This will be particularly effective where technology combinations are used, for example, drones capturing site data so that real time 3D models can be sent to robots and unmanned machines, from bulldozers to diggers, which will carry out the main demolition and construction work, with a human overseer.

Aerial construction will also become prevalent, as drones themselves are used to undertake construction, specialising initially in hard-to-reach or unsafe places, particularly those which are high up.

In the long-term, the bulk of decision making will move away from the human as we become an industry driven by better data and predictive analytics.

07. Construction will get faster, using 3D and 4D printing, and self-transforming objects which self-assemble

Laser scanning and point clouds are already bringing new accuracy and efficiency. Advances in 3D printing – also known as additive manufacturing – mean that we will soon be able to print bespoke components onsite rather than ordering them and waiting for them to be delivered. 3D printing entire buildings is the next step, something which will have significant implications for the affordability of housing, the ease with which they can be made bespoke and how quickly they can be built. With every major urban economy in the world facing a housing shortage, the potential this offers is significant.

Experiments are already underway and prototypes are being constructed, for example, a team at USC are working on a 3D printer which aims to build a whole house including electricity and plumbing in under 24 hours⁹; in Amsterdam, a team of

⁹ <https://viterbi.usc.edu/news/news/2014/3d-printing-a.htm>

architects has constructed the Print Canal House¹⁰, a micro house made using bio-based, renewable materials; while a Chinese company called WinSun claims already to be able to do it¹¹ at scale and affordably.

While its full potential is still being explored, and 3D printing is yet to change how the infrastructure and construction industry builds, it has actually been around for over 30 years. Indeed, scientists at the Massachusetts Institute of Technology (MIT) are already experimenting with 4D printing¹², an expression which refers to self-transforming objects. It involves printing a small item that responds to a stimulus, for example a change in heat, sound, or moisture levels, to alter its shape. This could lead to the creation of smart objects, from roads to pipes, that can react to changing environmental conditions.

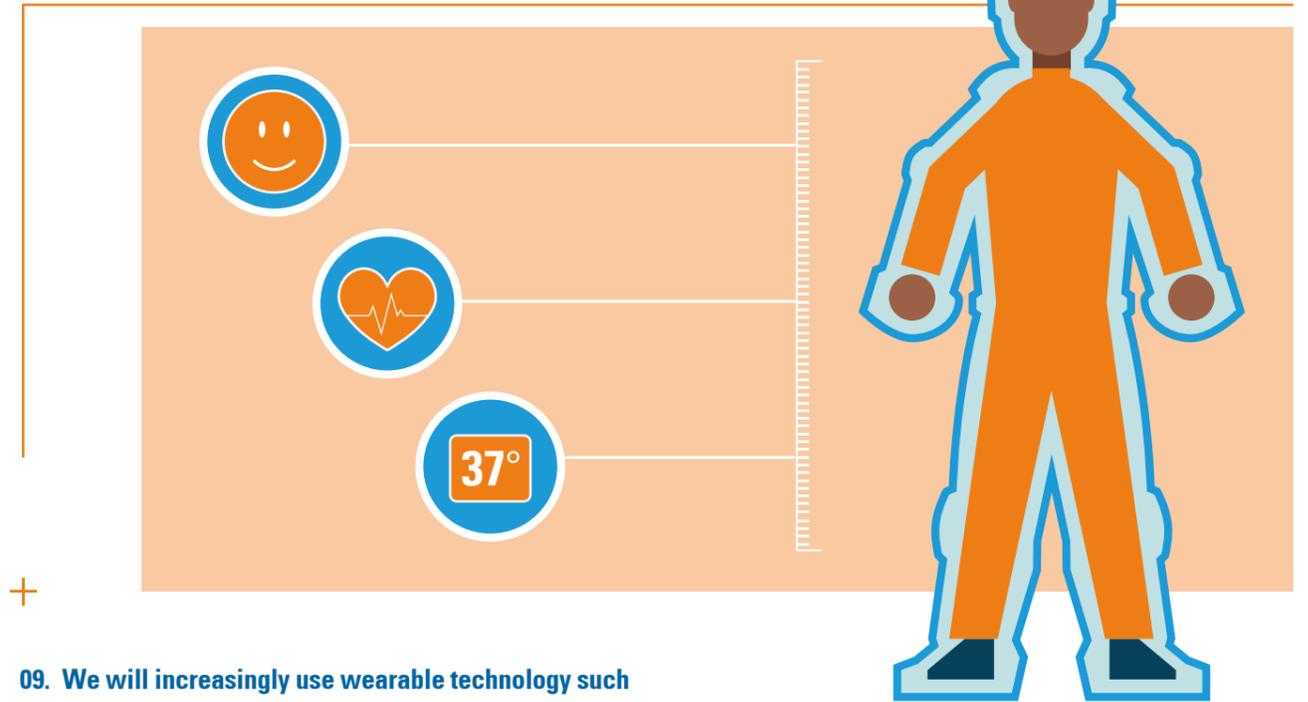
MIT is also working on reconfigurable robots¹³ which have the potential to result in self-assembling objects, which could be useful for installing infrastructure in hard to reach places for instance. The work has already produced M Blocks, a system of discrete cubes guided by algorithms, which can move independently to form a structure, then break apart and reform into a new structure. Scientists have suggested that the current design could be refined to be used to temporarily repair bridges during emergencies, for example. However, made to work at scale, this could be a massive change in the way we design, build and operate our structures. Although it is some way in the future, it could bring in buildings which are able to respond to their environments, and give those living and working in them the power to change the building to better suit their needs.

08. New, disruptive ideas will emerge, for making mass transit faster, safer and less damaging to the environment

Beyond autonomous vehicles, which will see vehicles collaborating to allow the creation of safer, faster transport systems with much greater capacity, many believe that we will also see a working Hyperloop – a new method of transportation which relies on electric propulsion and levitation to send pods from city to city at speeds of up to 760 miles per hour, within the next decade.

Balfour Beatty believes that other new, disruptive ideas for making mass transit faster, safer and less damaging to the environment will emerge, providing a response to congestion, cities dominated by vehicles and issues such as noise and air pollution. Airbus, for example, has suggested that aircraft could, by 2050¹⁴, be catapulted into the sky using a concept called ‘eco-climb’, building on the idea which has been used by the military to launch craft from aircraft carriers, for several decades. Airbus has also suggested the use of ‘express skyways’, which would see planes fly in formation, while ‘free-glide’ landings would create less noise and pollution as aircraft approach the runway.

To be able to embrace these technologies as they emerge, countries around the world need to be ready with the various regulatory frameworks required and infrastructure and construction companies need to ensure that they have the skills, knowledge and systems in place to build the associated infrastructure.



09. We will increasingly use wearable technology such as exoskeletons

Exoskeletons have been in use for some time in other areas of society in the form of powered walking suits which help people learn to walk again after serious accidents, for example. Their use in construction, in terms of improving health and safety for workers operating heavy machines and productivity is now beginning to be realised.

Balfour Beatty’s subsidiary, Gammon Construction¹⁵ is using exoskeleton systems in Hong Kong to increase productivity and make easier tasks involving heavy lifting and repetition. While we believe the use of exoskeletons will have been mainstreamed before 2050, it is also our view that other forms of advanced clothing will emerge, which will help the industry carry out a range of tasks and keep workers safe and healthy.

We believe that focus in the future will move from safety to health and wellbeing. Wearable health tech will become standard and tailored wellbeing packages will be offered to employees. The industry will become known as being the No.1 industry for those putting health and wellbeing as their top priority, in essence creating a super workforce which leads, amongst other outcomes, to improved productivity.

Wearable technology will become the norm

¹⁰ <http://3dprintcanalhouse.com>

¹¹ Xinhua News, April 25 2014

¹² <http://www.selfassemblylab.net/4DPrinting.php>

¹³ Larry Hardesty, MIT News Office, October 4, 2013

¹⁴ Airbus 2050 Vision for “Smarter Skies”, June 2011

¹⁵ Balfour Beatty is a 50% shareholder in Gammon Construction, based in Hong Kong



Neural control will help humans operate robots or exoskeletons

10. Direct neural control over devices and vehicles will be accessible to the industry

Although it may sound like something out of science fiction, direct neural control already exists in primitive forms, enabling amputees to control prosthetic devices using direct neural signals, for example. Research teams at Tianjing's Nankai University¹⁶ and Berlin's Free University have already developed cars that can be driven using elements of mind control via sensors in a gadget worn on the head, although experiments are in the early stages. It is not inconceivable that by 2050, the technology will have evolved enough to deliver a neural control system which delivers for the construction industry, via implantable microchips – or even without them. Under this scenario, “digital people” would be able to use direct neural input to disseminate information and control devices such as “hands free” robots or exoskeletons.

Privacy issues and dangers surrounding sinister uses, such as hackers accessing the information needed to control or manipulate the microchipped person or people, would need to be overcome, but the use of potential direct neural control for improving the safety of workers and improving efficiency of construction is significant.

¹⁶ <http://www.reuters.com/article/us-china-brainpower-car-idUSKBN0TQ23620151207>

The challenges associated with digitisation

While harnessing the potential of new technology will bring significant benefits to both society and the infrastructure and construction industry, there will be hurdles to overcome for all parties. For the industry itself, the main challenge lies in efficiently absorbing new technology and becoming more adept at doing it quickly. However, there is also a number of higher-level points which policy makers, regulators and society more broadly will have to respond to.

Increased demands on energy consumption

The amount of energy data centres use is already around 3% of the world's electricity, at 416.2 terawatt hours. It accounts for around 2% of global greenhouse gas emissions, giving it the same carbon footprint as the aviation industry – and it is predicted to triple in the next decade¹⁷. Energy grids in many countries are already reaching the limits of their capacity. We are on the cusp of new technologies such as the Internet of Things and virtual reality that will require even more resources and see a massive increase in data usage. To address this, infrastructure design will need to take account of climate projections and impacts. The use of renewable energy may need to significantly increase and new technologies and ways of storing data will have to be developed.

To play their part in this, regulators and policy makers will themselves need to upskill and ensure that they are providing frameworks which allow industry and digital solutions to flourish, while incentivising the development of new energy solutions and ensuring that resources are not irrevocably depleted.

Processing and using the data in real time will get more difficult

There are currently 3.5 billion sensors in the world, linking objects to the internet. This is projected to increase to 1 trillion by 2022¹⁸ as the Internet of Things becomes a reality and objects from buildings and vehicles to clothes and furniture become digitally connected. With so much data being created, there is a risk that we may reach saturation point in what can be processed, understood and used. However it is only by finding ways to process all the available data that we can put it to best use in understanding our customers' needs, planning investments and predicting better what the impact would be of particular courses of action.

For the construction and infrastructure industry, aggregating and making sense of so much data from so many sources will require new software and algorithms, skilled data analysts, better information management and insight and the creation of mega databases which understand every part of the built environment. Data gathering and storage will have to become more intelligent to ensure that information is being used to drive improvements in the way systems operate and infrastructure is used and built.

The debate around privacy vs. the benefits of data will become more heated

While smart homes, connected vehicles and so on will offer numerous benefits, they will also increasingly come up against privacy requirements as people begin to question the amount of data all the sensors around the buildings they live and work in are collecting and what it is being used for. For example, German researchers from Muenster University of Applied Sciences demonstrated in 2012 that smart meters monitoring electricity usage in homes leak data that could reveal what programmes are being watched. While this is a relatively benign example, with the worst outcomes likely to be an individual's data being sold to advertisers, some of the data being produced by sensors will be more sensitive in nature. Demands for regulation around privacy are likely to escalate and infrastructure companies embedding sensors will need to ensure that they respond to the privacy challenge by ensuring the highest levels of encryption and anonymisation.

Borders will become blurred in a number of different areas

The boundary between the physical and digital worlds will become harder to define as digital becomes more and more prevalent in all aspects of daily life. This will take a number of different forms, for example:

- National borders will become more blurred as countries become more dependent on shared infrastructure for their national internet and satellite systems.
- Advances in technology will also increasingly blur the lines between traditional sectors. The business landscape will become less defined and predictable and there will be more cross-industry competition as companies try new models and products and develop multiple fields of expertise. Incumbents

will need to become agile – there will be no room, or time, for complacency.

- The increasingly seamless interplay between virtual and physical spaces will begin to merge work, leisure and travel.
- Autonomous non-human intelligence and humans using wearable technology, or integrated technology such as replacement, robotic limbs or organs will also challenge conventional definitions of human and machine.
- Boundaries between public and private information will also become less defined.

Cyber-security will become more important

The future is data-rich. However, increasing the use of digital technologies also increases the risks of cyber-attack, a risk that will continue to grow along with our reliance on technology as we have already seen in 2017 in the May "WannaCry" ransomware that hit 150 countries - the worst attack ever on critical infrastructure. Regular assaults are likely to become the norm as criminal gangs find new ways to exploit cyber weapons which exploit old, weak and under-protected software systems.

For the infrastructure and construction industry, this poses a particular challenge. Large projects and the increasingly global nature of schemes which see suppliers and contractors from a number of different countries collaborating depend on the collating and sharing of large amounts of data about the site, systems and the infrastructure being built. Internet connected solutions and remotely accessible systems such as BIM, open up the risk of cyber-attack.

In some cases, for example, around critical infrastructure facilities such as hospitals and energy plants, or government sites, the sensitive data involved can have national security implications. At particular risk are Building Management Systems (BMS), on which many hospitals, government buildings, banks, research facilities and prisons are increasingly reliant. These use sensors in walls, ceilings, lights and even desks for example, to control systems such as heating and security features such as door opening. They are connected to the corporate network and the internet and as such are vulnerable to what are becoming increasingly frequent and sophisticated attacks. The potential consequences of attackers disrupting power or water supplies for example, are significant.

A few, recent examples in addition to WannaCry include:

- A 2014 spear phishing attack (using fraudulent emails containing malware) on a steel mill in Germany saw malware loaded onto the company computer. Via the plant's business network, hackers took over most of the plant's control systems and stopped a blast furnace being shut down, causing significant damage.
- At least two Ukrainian power stations, the Prykarpattya Oblenergo and Kyivoblenergo utilities, were successfully attacked in December 2015, cutting seven or more 110 kV and 23 35 kV substations. These attacks also used malware and left 80,000 customers without power in what was a coordinated attack where operatives were prevented from accessing the systems to restore them via a variety of means including wiped servers.
- The NHS in England has repeatedly fallen victim to ransomware attacks, where hackers hold building owners to ransom by infecting their IT systems with viruses which they remove on payment. Hospitals represent an easy target because of the high stakes if hackers cut access to essential equipment and patient records. One of these attacks caused four days of disruption at the hospitals of the Northern Lincolnshire and Goole NHS trust in 2016, with 2,800 appointments cancelled.

Governments will have to scale up and invest in national cyber defence programmes to protect critical infrastructure. However the infrastructure industry must take its share of responsibility in tackling these issues. It must ensure that data is treated as a major asset. Cyber risk has to be programmed in, much as any other risk would be. Governance must be strong and best practice embedded and rigorously followed. Employees must be properly trained and security software kept up to date. This is especially the case in markets such as the UK, where the supply chain is fragmented and reliant on SMEs, which are likely to be less data aware than larger players. Smart systems should be kept separate from corporate networks.

Customers will rightly become increasingly demanding on cyber-security compliance and the legal implications given the significance of some of the data involved. The infrastructure industry must take the risks seriously and be proactive in tackling them.

¹⁷ The Independent, 23 January 2016

¹⁸ Deep Shift Technology Tipping Points and Societal Impact, World Economic Forum, 2015

Conclusion

Nobody knows for certain where the Digital Revolution will take us, but it holds massive potential to transform both the industry and the built environment.

The infrastructure and construction industry has not yet seen the same rate of transformation as some other industries, but that is beginning to change – and the change will be both significant and unstoppable. “Big data” will facilitate more evidence-based decisions and a better understanding of the customer, while technologies currently in their infancy will mature and new technologies will enable us to deliver faster, better and safer.

The rapid pace of digital change is only set to increase. It will redefine infrastructure and construction and the industry will need to anticipate that change and adapt quickly, becoming more innovative and less risk-averse, in response. We must be ready to embrace new technologies as well as new possibilities and ideas as they emerge. But we must be prepared to balance the benefits with the risks.

Balfour Beatty believes that the infrastructure industry must modernise in order to secure its own future. Those companies at the forefront of the digital revolution, which integrate new technologies most effectively, updating their business capabilities and their offer, will reap the biggest rewards.





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